AFRL-ML-WP-TR-2006-4059

NONMETALS TEST AND EVALUATION

Delivery Order 0003: Fuel System Materials Compatibility Testing of Fuel Additives for Reducing the Amount of Small Particulate in Turbine Engine Exhaust

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OCTOBER 2005

Final Report for 16 July 2001 – 30 September 2005

STINFO FINAL REPORT

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750

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PAO Case Number: AFRL/WS 06-0557, 27 Feb 2006.

THIS TECHNICAL REPORT IS APPROVED FOR PUBLICATION.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
October 2005	Final	07/16/2001 – 09/30/2005

4. TITLE AND SUBTITLE
NONMETALS TEST AND EVALUATION
Delivery Order 0003: Fuel System Materials Compatibility Testing of Fuel Additives for Reducing the Amount of Small Particulate in Turbine Engine Exhaust

5a. CONTRACT NUMBER
F33615-00-D-5600-0003

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62102F

6. AUTHOR(S)
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5d. PROJECT NUMBER
4349

5e. TASK NUMBER
S4

5f. WORK UNIT NUMBER
03

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Dayton Research Institute
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Dayton, OH 45469-0130

8. PERFORMING ORGANIZATION REPORT NUMBER
UDR-TR-2005-00181

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Materials and Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson AFB, OH 45433-7750

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL-ML-WP

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-ML-WP-TR-2006-4059

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Report contains color.

14. ABSTRACT (*Maximum 200 words*)
Environmental legislation is being drafted by the EPA to reduce small particles in turbine engine exhaust. Six of the most promising fuel additives were chosen for a comparative evaluation as to the material compatibility with the non-metallic materials present on aircraft. These additives were added to JP-8+100 fuel prior to testing. In general, all results showed no significant concerns with the materials tested.

15. SUBJECT TERMS
Particulates, emissions, JP-8+100, fluid compatibility, non-metallics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
a. REPORT	b. ABSTRACT	c. THIS PAGE			James J. Mazza
Unclassified	Unclassified	Unclassified	SAR	50	19b. TELEPHONE NUMBER *(Include Area Code)* N/A

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

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PREFACE

This effort was initiated in July 2001 on Air Force Contract F33615-00-D-5600, DO 0003. All technical work was completed in September 2005. The work was administered by the Air Force Research Laboratory, Materials and Manufacturing Directorate, Systems Support Division, Wright-Patterson AFB, OH. Mr. James Mazza (AFRL/MLSA) was the contract monitor. Mr. Alan Fletcher (AFRL/MLSA) acted as Project Engineer.

This work was conducted by the University of Dayton Research Institute (UDRI) under the general supervision of Susan Saliba, Program Manager. Personnel who made major contributions to the success of this program include Messrs. Bill Fortener, John Conner, Tim Montavon, Wesley Waldron, and Don Byrge. Ms. Jeanne Miller of UDRI was responsible for the organization and final preparation of this final report. This report was submitted by the authors in October 2005. The contractor's report number is UDR-TR-2005-00181.

SECTION 1
INTRODUCTION

Environmental legislation is being drafted by the Environmental Protection Agency (EPA) to reduce small particles in turbine engine exhaust. To prepare for this change, additives to reduce the particulates in turbine engine exhaust were investigated. The six most promising additives were then chosen for further testing. AFRL/PR submitted a test plan to the UDRI to test material compatibility with six baseline JP-8+100 fuels that had these candidate additives included. The six additives were identified as follows: RXP, Winns, #4, #5, #6, and PA-5. Additionally, a baseline JP-8+100 fuel with no additives was tested as the control.

SECTION 2
PROCEDURE

All testing was in accordance with established ASTM and SAE test procedures outlined below. The materials tested were comprised of three adhesives, two fuel bladder materials, four coatings, six sealants, three composite materials, one foam material, four specific types of o-rings, two hose materials, and four wire insulation materials. Required testing included the following:

Adhesives	
• Lap Shear	ASTM D 1002
Fuel Bladders	
• Tensile Strength & Elongation	ASTM D 1414
• Volume Swell	ASTM D 471
Coatings	
• Pencil Hardness	ASTM D 3363
• Tape Adhesion	ASTM D 3359
• Taber Test	ASTM D 4060
Sealants	
• Peel Strength	SAE AS5127/1
• Hardness, Shore A	ASTM D 2240 SAE AS5127/1
• Tensile Strength & Elongation	ASTM D 412 SAE AS5127/1
• Volume Swell	ASTM D 471 SAE AS5127/1
Composite Materials	
• Interlaminar Shear	ASTM D 790
Foam Material	
• Tensile Strength & Elongation	ASTM D 412
• Resistivity	ASTM D 257
O-rings	
• Hardness, Shore M	ASTM D 2240
• Tensile Strength & Elongation	ASTM D 1414
• Compression Set	ASTM D 395
• Volume Swell	ASTM D 471

Hose Material

- Hardness, Shore A — ASTM D 2240
- Tensile Strength & Elongation — ASTM D 412
- Volume Swell — ASTM D 471

Wire Insulation

- Tensile Strength & Elongation — ASTM D 412

SECTION 3
TEST RESULTS

1. The results of the material compatibility with the fuel particulate emission additives are contained in Tables 1 through 9.
2. There were no significant concerns raised after testing all three adhesives in the additive-enhanced fuels and comparing to the control fuel.
3. There were no significant concerns raised after testing both bladder materials in the additive-enhanced fuels and comparing to the control fuel.
4. There were no significant concerns raised after testing all four coatings in the additive-enhanced fuels and comparing to the control fuel. One pencil hardness result for EC 776 aged in fuel with additive #4 had a result of HB. All other results for all four coatings in all test fuels ranged from 2H to greater than 6H. All tape adhesion tests passed. In addition, the wear index results for MIL-P-24441 ranged from 0.13 to 0.39.
5. There were no significant concerns raised after testing all six sealants in the additive-enhanced fuels and comparing to the control fuel.
6. There were no significant concerns raised after testing all three composite materials in the additive-enhanced fuels and comparing to the control fuel.
7. There were no significant concerns raised after testing the foam material in the additive-enhanced fuels and comparing to the control fuel.
8. There were no significant concerns raised after testing all four o-rings in the additive-enhanced fuels and comparing to the control fuel, with the exception of the compression set results for the V1226 fluorocarbon o-ring aged in the #5 additive-enhanced fuel. The result of 44.3% was double that of the average of the other six fuels of 22.2%.
9. There were no significant concerns raised after testing both hose materials in the additive-enhanced fuels and comparing to the control fuel.
10. There were no significant concerns raised after testing all four wire insulation materials in the additive-enhanced fuels and comparing to the control fuel.

TABLE 1

ADHESIVES

Material Description	Test	Conditioning	Results
FM 47 (Vinyl Phenolic)	Lap Shear	Unaged	3015 psi
		7d/200°F/JP-8+100 (Control)	2111 psi
		7d/200°F/Control + #1 (RXP)	1812 psi
		7d/200°F/Control + #2 (Winns)	2089 psi
		7d/200°F/JP-8 + Lubrizol (PA-5)	2137 psi
		7d/200°F/Control + #4 (PRSF Additive)	1829 psi
		7d/200°F/Control + #5 (PRSF Additive)	1980 psi
		7d/200°F/Control + #6 (PRSF Additive)	1961 psi
Epon 828/DTA (Epoxy)	Lap Shear	Unaged	4430 psi
		7d/200°F/JP-8+100 (Control)	3676 psi
		7d/200°F/Control + #1 (RXP)	3532 psi
		7d/200°F/Control + #2 (Winns)	3436 psi
		7d/200°F/JP-8 + Lubrizol (PA-5)	3586 psi
		7d/200°F/Control + #4 (PRSF Additive)	3416 psi
		7d/200°F/Control + #5 (PRSF Additive)	3595 psi
		7d/200°F/Control + #6 (PRSF Additive)	3741 psi

TABLE 1 (Continued)

ADHESIVES

Material Description	Test	Conditioning	Results
Scotchweld AF-10 (Nitrile Phenolic)	Lap Shear	Unaged	3554 psi
		7d/200°F/JP-8+100 (Control)	3808 psi
		7d/200°F/Control + #1 (RXP)	3919 psi
		7d/200°F/Control + #2 (Winns)	3509 psi
		7d/200°F/JP-8 + Lubrizol (PA-5)	3392 psi
		7d/200°F/Control + #4 (PRSF Additive)	3840 psi
		7d/200°F/Control + #5 (PRSF Additive)	3731 psi
		7d/200°F/Control + #6 (PRSF Additive)	3685 psi

TABLE 2

BLADDER TANKS

Material Description	Test	Conditioning	Results
EF 51956 (Nitrile)	Tensile Strength / Elongation	Unaged	2501 psi / 348%
		7d/200°F/JP-8+100 (Control)	1969 psi / 232%
		7d/200°F/Control + #1 (RXP)	1928 psi / 220%
		7d/200°F/Control + #2 (Winns)	1834 psi / 233%
		7d/200°F/JP-8 + Lubrizol (PA-5)	1939 psi / 340%
		7d/200°F/Control + #4 (PRSF Additive)	2099 psi / 261%
		7d/200°F/Control + #5 (PRSF Additive)	1958 psi / 235%
		7d/200°F/Control + #6 (PRSF Additive)	1906 psi / 229%
	Volume Swell	7d/200°F/JP-8+100 (Control)	0.01%
		7d/200°F/Control + #1 (RXP)	-0.28%
		7d/200°F/Control + #2 (Winns)	-0.44%
		7d/200°F/JP-8 + Lubrizol (PA-5)	0.94%
		7d/200°F/Control + #4 (PRSF Additive)	-0.63%
		7d/200°F/Control + #5 (PRSF Additive)	-1.50%
		7d/200°F/Control + #6 (PRSF Additive)	-0.21%

TABLE 2 (Continued)

BLADDER TANKS

Material Description	Test	Conditioning	Results
EF 5904C (Polyurethane)	Tensile Strength / Elongation	Unaged	2773 psi / 307%
		7d/200°F/JP-8+100 (Control)	2437 psi / 478%
		7d/200°F/Control + #1 (RXP)	2497 psi / 501%
		7d/200°F/Control + #2 (Winns)	1989 psi / 586%
		7d/200°F/JP-8 + Lubrizol (PA-5)	2270 psi / 518%
		7d/200°F/Control + #4 (PRSF Additive)	2166 psi / 534%
		7d/200°F/Control + #5 (PRSF Additive)	2253 psi / 532%
		7d/200°F/Control + #6 (PRSF Additive)	2086 psi / 538%
	Volume Swell	7d/200°F/JP-8+100 (Control)	17.6%
		7d/200°F/Control + #1 (RXP)	11.3%
		7d/200°F/Control + #2 (Winns)	23.9%
		7d/200°F/JP-8 + Lubrizol (PA-5)	29.0%
		7d/200°F/Control + #4 (PRSF Additive)	28.7%
		7d/200°F/Control + #5 (PRSF Additive)	19.8%
		7d/200°F/Control + #6 (PRSF Additive)	16.1%

TABLE 3

COATINGS

Material Description	Test	Conditioning	Results
MIL-S-4383 (EC 776) (Nitrile)	Pencil Hardness	Unaged	2H*
		7d/200°F/JP-8+100 (Control)	2H*
		7d/200°F/Control + #1 (RXP)	2H*
		7d/200°F/Control + #2 (Winns)	2H*
		7d/200°F/JP-8 + Lubrizol (PA-5)	>6H*
		7d/200°F/Control + #4 (PRSF Additive)	HB*
		7d/200°F/Control + #5 (PRSF Additive)	2H*
		7d/200°F/Control + #6 (PRSF Additive)	2H*
	Tape Adhesion	Unaged	Passed
		7d/200°F/JP-8+100 (Control)	Passed
		7d/200°F/Control + #1 (RXP)	Passed
		7d/200°F/Control + #2 (Winns)	Passed
		7d/200°F/JP-8 + Lubrizol (PA-5)	Passed
		7d/200°F/Control + #4 (PRSF Additive)	Passed
		7d/200°F/Control + #5 (PRSF Additive)	Passed
		7d/200°F/Control + #6 (PRSF Additive)	Passed

*NOTE: 6B - 5B - 4B - 3B - 2B – B – HB - F- H - 2H - 3H - 4H - 5H - 6H
Softer Harder

TABLE 3 (Continued)

COATINGS

Material Description	Test	Conditioning	Results
MIL-C-27725 (Polyurethane)	Pencil Hardness	Unaged	>6H*
		7d/200°F/JP-8+100 (Control)	>6H*
		7d/200°F/Control + #1 (RXP)	>6H*
		7d/200°F/Control + #2 (Winns)	4H*
		7d/200°F/JP-8 + Lubrizol (PA-5)	>6H*
		7d/200°F/Control + #4 (PRSF Additive)	6H*
		7d/200°F/Control + #5 (PRSF Additive)	6H*
		7d/200°F/Control + #6 (PRSF Additive)	6H*
	Tape Adhesion	Unaged	Passed
		7d/200°F/JP-8+100 (Control)	Passed
		7d/200°F/Control + #1 (RXP)	Passed
		7d/200°F/Control + #2 (Winns)	Passed
		7d/200°F/JP-8 + Lubrizol (PA-5)	Passed
		7d/200°F/Control + #4 (PRSF Additive)	Passed
		7d/200°F/Control + #5 (PRSF Additive)	Passed
		7d/200°F/Control + #6 (PRSF Additive)	Passed

*NOTE: 6B - 5B - 4B - 3B - 2B – B – HB - F- H - 2H - 3H - 4H - 5H - 6H
Softer Harder

TABLE 3 (Continued)

COATINGS

Material Description	Test	Conditioning	Results
BMS 10-20 (Epoxy)	Pencil Hardness	Unaged	>6H*
		7d/200°F/JP-8+100 (Control)	>6H*
		7d/200°F/Control + #1 (RXP)	>6H*
		7d/200°F/Control + #2 (Winns)	6H*
		7d/200°F/JP-8 + Lubrizol (PA-5)	>6H*
		7d/200°F/Control + #4 (PRSF Additive)	6H*
		7d/200°F/Control + #5 (PRSF Additive)	6H*
		7d/200°F/Control + #6 (PRSF Additive)	6H*
	Tape Adhesion	Unaged	Passed
		7d/200°F/JP-8+100 (Control)	Passed
		7d/200°F/Control + #1 (RXP)	Passed
		7d/200°F/Control + #2 (Winns)	Passed
		7d/200°F/JP-8 + Lubrizol (PA-5)	Passed
		7d/200°F/Control + #4 (PRSF Additive)	Passed
		7d/200°F/Control + #5 (PRSF Additive)	Passed
		7d/200°F/Control + #6 (PRSF Additive)	Passed

*NOTE: 6B - 5B - 4B - 3B - 2B – B – HB - F- H - 2H - 3H - 4H - 5H - 6H
Softer Harder

TABLE 3 (Continued)

COATINGS

Material Description	Test	Conditioning	Results
MIL-P-24441 (Epoxy Polyamide)	Pencil Hardness	Unaged	>6H*
		7d/200°F/JP-8+100 (Control)	>6H*
		7d/200°F/Control + #1 (RXP)	>6H*
		7d/200°F/Control + #2 (Winns)	5H*
		7d/200°F/JP-8 + Lubrizol (PA-5)	>6H*
		7d/200°F/Control + #4 (PRSF Additive)	5H*
		7d/200°F/Control + #5 (PRSF Additive)	6H*
		7d/200°F/Control + #6 (PRSF Additive)	6H*
	Tape Adhesion	Unaged	Passed
		7d/200°F/JP-8+100 (Control)	Passed
		7d/200°F/Control + #1 (RXP)	Passed
		7d/200°F/Control + #2 (Winns)	Passed
		7d/200°F/JP-8 + Lubrizol (PA-5)	Passed
		7d/200°F/Control + #4 (PRSF Additive)	Passed
		7d/200°F/Control + #5 (PRSF Additive)	Passed
		7d/200°F/Control + #6 (PRSF Additive)	Passed

*NOTE: 6B - 5B - 4B - 3B - 2B – B – HB - F- H - 2H - 3H - 4H - 5H - 6H
Softer Harder

TABLE 3 (Continued)
COATINGS

Material Description	Test	Conditioning	Results
MIL-P-24441 (Epoxy Polyamide)	Taber Test (Wear Index)	Unaged	0.27
		7d/200°F/JP-8+100 (Control)	0.18
		7d/200°F/Control + #1 (RXP)	0.39
		7d/200°F/Control + #2 (Winns)	0.26
		7d/200°F/JP-8 + Lubrizol (PA-5)	0.13
		7d/200°F/Control + #4 (PRSF Additive)	0.19
		7d/200°F/Control + #5 (PRSF Additive)	0.21
		7d/200°F/Control + #6 (PRSF Additive)	0.26

TABLE 4

SEALANTS

Material Description	Test	Conditioning	Results
PR 1422 B-2 (MIL-S-8802) (Polysulfide)	Tensile Strength / Elongation	Unaged	342 psi / 336%
		7d/200°F/JP-8+100 (Control)	313 psi / 368%
		7d/200°F/Control + #1 (RXP)	330 psi / 330%
		7d/200°F/Control + #2 (Winns)	313 psi / 309%
		7d/200°F/JP-8 + Lubrizol (PA-5)	386 psi / 313%
		7d/200°F/Control + #4 (PRSF Additive)	353 psi / 319%
		7d/200°F/Control + #5 (PRSF Additive)	363 psi / 343%
		7d/200°F/Control + #6 (PRSF Additive)	353 psi / 301%
	Volume Swell	7d/200°F/JP-8+100 (Control)	1.0%
		7d/200°F/Control + #1 (RXP)	1.0%
		7d/200°F/Control + #2 (Winns)	1.3%
		7d/200°F/JP-8 + Lubrizol (PA-5)	-0.3%
		7d/200°F/Control + #4 (PRSF Additive)	0.5%
		7d/200°F/Control + #5 (PRSF Additive)	0.4%
		7d/200°F/Control + #6 (PRSF Additive)	0.4%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1422 B-2 (MIL-S-8802) (Polysulfide)	Shore A Hardness	Unaged	47
		7d/200°F/JP-8+100 (Control)	53
		7d/200°F/Control + #1 (RXP)	52
		7d/200°F/Control + #2 (Winns)	53
		7d/200°F/JP-8 + Lubrizol (PA-5)	59
		7d/200°F/Control + #4 (PRSF Additive)	55
		7d/200°F/Control + #5 (PRSF Additive)	53
		7d/200°F/Control + #6 (PRSF Additive)	56
	Peel Strength (MIL-C-27725)	Unaged	36 lb / 100%
		7d/200°F/JP-8+100 (Control)	36 lb / 100%
		7d/200°F/Control + #1 (RXP)	38 lb / 100%
		7d/200°F/Control + #2 (Winns)	39 lb / 100%
		7d/200°F/JP-8 + Lubrizol (PA-5)	36 lb / 100%
		7d/200°F/Control + #4 (PRSF Additive)	39 lb / 100%
		7d/200°F/Control + #5 (PRSF Additive)	46 lb / 100%
		7d/200°F/Control + #6 (PRSF Additive)	42 lb / 100%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1440 B-2 (MIL-S-8802) (Polysulfide)	Tensile Strength / Elongation	Unaged	450 psi / 287%
		7d/200°F/JP-8+100 (Control)	384 psi / 197%
		7d/200°F/Control + #1 (RXP)	412 psi / 230%
		7d/200°F/Control + #2 (Winns)	403 psi / 230%
		7d/200°F/JP-8 + Lubrizol (PA-5)	481 psi / 301%
		7d/200°F/Control + #4 (PRSF Additive)	430 psi / 229%
		7d/200°F/Control + #5 (PRSF Additive)	424 psi / 239%
		7d/200°F/Control + #6 (PRSF Additive)	403 psi / 221%
	Volume Swell	7d/200°F/JP-8+100 (Control)	-1.7%
		7d/200°F/Control + #1 (RXP)	-1.3%
		7d/200°F/Control + #2 (Winns)	-0.9%
		7d/200°F/JP-8 + Lubrizol (PA-5)	-0.3%
		7d/200°F/Control + #4 (PRSF Additive)	-1.0%
		7d/200°F/Control + #5 (PRSF Additive)	-0.7%
		7d/200°F/Control + #6 (PRSF Additive)	-1.3%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1440 B-2 (MIL-S-8802) (Polysulfide)	Shore A Hardness	Unaged	45
		7d/200°F/JP-8+100 (Control)	50
		7d/200°F/Control + #1 (RXP)	54
		7d/200°F/Control + #2 (Winns)	54
		7d/200°F/JP-8 + Lubrizol (PA-5)	55
		7d/200°F/Control + #4 (PRSF Additive)	55
		7d/200°F/Control + #5 (PRSF Additive)	50
		7d/200°F/Control + #6 (PRSF Additive)	53
	Peel Strength (MIL-C-27725)	Unaged	49 lb / 100%
		7d/200°F/JP-8+100 (Control)	31 lb / 96%
		7d/200°F/Control + #1 (RXP)	30 lb / 93%
		7d/200°F/Control + #2 (Winns)	31 lb / 100%
		7d/200°F/JP-8 + Lubrizol (PA-5)	35 lb / 100%
		7d/200°F/Control + #4 (PRSF Additive)	30 lb / 71%
		7d/200°F/Control + #5 (PRSF Additive)	35 lb / 100%
		7d/200°F/Control + #6 (PRSF Additive)	41 lb / 100%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
Q-4-2817 / 1200 Primer	Tensile Strength / Elongation	Unaged	332 psi / 179%
		7d/200°F/JP-8+100 (Control)	316 psi / 157%
		7d/200°F/Control + #1 (RXP)	336 psi / 172%
		7d/200°F/Control + #2 (Winns)	309 psi / 152%
		7d/200°F/JP-8 + Lubrizol (PA-5)	312 psi / 164%
		7d/200°F/Control + #4 (PRSF Additive)	282 psi / 132%
		7d/200°F/Control + #5 (PRSF Additive)	298 psi / 137%
		7d/200°F/Control + #6 (PRSF Additive)	340 psi / 149%
	Volume Swell	7d/200°F/JP-8+100 (Control)	2.1%
		7d/200°F/Control + #1 (RXP)	1.8%
		7d/200°F/Control + #2 (Winns)	1.7%
		7d/200°F/JP-8 + Lubrizol (PA-5)	1.5%
		7d/200°F/Control + #4 (PRSF Additive)	2.3%
		7d/200°F/Control + #5 (PRSF Additive)	1.2%
		7d/200°F/Control + #6 (PRSF Additive)	1.5%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
Q-4-2817 / 1200 Primer	Shore A Hardness	Unaged	44
		7d/200°F/JP-8+100 (Control)	47
		7d/200°F/Control + #1 (RXP)	41
		7d/200°F/Control + #2 (Winns)	45
		7d/200°F/JP-8 + Lubrizol (PA-5)	40
		7d/200°F/Control + #4 (PRSF Additive)	46
		7d/200°F/Control + #5 (PRSF Additive)	46
		7d/200°F/Control + #6 (PRSF Additive)	45
	Peel Strength (MIL-C-27725)	Unaged	28 lb / 100%
		7d/200°F/JP-8+100 (Control)	15 lb / 100%
		7d/200°F/Control + #1 (RXP)	13 lb / 100%
		7d/200°F/Control + #2 (Winns)	21 lb / 100%
		7d/200°F/JP-8 + Lubrizol (PA-5)	14 lb / 100%
		7d/200°F/Control + #4 (PRSF Additive)	15 lb / 100%
		7d/200°F/Control + #5 (PRSF Additive)	19 lb / 100%
		7d/200°F/Control + #6 (PRSF Additive)	24 lb / 100%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 2911 (Polyurethane)	Tensile Strength / Elongation	Unaged	964 psi / 793%
		7d/200°F/JP-8+100 (Control)	903 psi / 792%
		7d/200°F/Control + #1 (RXP)	900 psi / 800%
		7d/200°F/Control + #2 (Winns)	677 psi / 720%
		7d/200°F/JP-8 + Lubrizol (PA-5)	635 psi / 669%
		7d/200°F/Control + #4 (PRSF Additive)	616 psi / 755%
		7d/200°F/Control + #5 (PRSF Additive)	797 psi / 790%
		7d/200°F/Control + #6 (PRSF Additive)	742 psi / 768%
	Volume Swell	7d/200°F/JP-8+100 (Control)	15.3%
		7d/200°F/Control + #1 (RXP)	13.5%
		7d/200°F/Control + #2 (Winns)	13.5%
		7d/200°F/JP-8 + Lubrizol (PA-5)	15.0%
		7d/200°F/Control + #4 (PRSF Additive)	15.2%
		7d/200°F/Control + #5 (PRSF Additive)	13.6%
		7d/200°F/Control + #6 (PRSF Additive)	15.3%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 2911 (Polyurethane)	Shore A Hardness	Unaged	60
		7d/200°F/JP-8+100 (Control)	54
		7d/200°F/Control + #1 (RXP)	44
		7d/200°F/Control + #2 (Winns)	48
		7d/200°F/JP-8 + Lubrizol (PA-5)	51
		7d/200°F/Control + #4 (PRSF Additive)	48
		7d/200°F/Control + #5 (PRSF Additive)	48
		7d/200°F/Control + #6 (PRSF Additive)	46
	Peel Strength (MIL-C-27725)	Unaged	27 lb / 100%
		7d/200°F/JP-8+100 (Control)	45 lb / 100%
		7d/200°F/Control + #1 (RXP)	19 lb / 100%
		7d/200°F/Control + #2 (Winns)	38 lb / 100%
		7d/200°F/JP-8 + Lubrizol (PA-5)	43 lb / 100%
		7d/200°F/Control + #4 (PRSF Additive)	40 lb / 100%
		7d/200°F/Control + #5 (PRSF Additive)	38 lb / 100%
		7d/200°F/Control + #6 (PRSF Additive)	40 lb / 100%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1828 B-2 (Polythioether)	Tensile Strength / Elongation	Unaged	398 psi / 306%
		7d/200°F/JP-8+100 (Control)	359 psi / 211%
		7d/200°F/Control + #1 (RXP)	416 psi / 241%
		7d/200°F/Control + #2 (Winns)	414 psi / 207%
		7d/200°F/JP-8 + Lubrizol (PA-5)	429 psi / 256%
		7d/200°F/Control + #4 (PRSF Additive)	333 psi / 208%
		7d/200°F/Control + #5 (PRSF Additive)	390 psi / 236%
		7d/200°F/Control + #6 (PRSF Additive)	439 psi / 250%
	Volume Swell	7d/200°F/JP-8+100 (Control)	8.3%
		7d/200°F/Control + #1 (RXP)	8.5%
		7d/200°F/Control + #2 (Winns)	9.6%
		7d/200°F/JP-8 + Lubrizol (PA-5)	7.8%
		7d/200°F/Control + #4 (PRSF Additive)	10.0%
		7d/200°F/Control + #5 (PRSF Additive)	8.2%
		7d/200°F/Control + #6 (PRSF Additive)	8.2%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1828 B-2 (Polythioether)	Shore A Hardness	Unaged	53
		7d/200°F/JP-8+100 (Control)	42
		7d/200°F/Control + #1 (RXP)	42
		7d/200°F/Control + #2 (Winns)	42
		7d/200°F/JP-8 + Lubrizol (PA-5)	43
		7d/200°F/Control + #4 (PRSF Additive)	40
		7d/200°F/Control + #5 (PRSF Additive)	37
		7d/200°F/Control + #6 (PRSF Additive)	40
	Peel Strength (MIL-C-27725)	Unaged	58 lb / 100%
		7d/200°F/JP-8+100 (Control)	35 lb / 100%
		7d/200°F/Control + #1 (RXP)	40 lb / 100%
		7d/200°F/Control + #2 (Winns)	41 lb / 100%
		7d/200°F/JP-8 + Lubrizol (PA-5)	35 lb / 100%
		7d/200°F/Control + #4 (PRSF Additive)	39 lb / 100%
		7d/200°F/Control + #5 (PRSF Additive)	44 lb / 100%
		7d/200°F/Control + #6 (PRSF Additive)	44 lb / 100%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1776 B-1/2 (AMS 3265) (Polysulfide)	Tensile Strength / Elongation	Unaged	229 psi / 508%
		7d/200°F/JP-8+100 (Control)	184 psi / 522%
		7d/200°F/Control + #1 (RXP)	162 psi / 380%
		7d/200°F/Control + #2 (Winns)	171 psi / 636%
		7d/200°F/JP-8 + Lubrizol (PA-5)	175 psi / 556%
		7d/200°F/Control + #4 (PRSF Additive)	177 psi / 639%
		7d/200°F/Control + #5 (PRSF Additive)	201 psi / 444%
		7d/200°F/Control + #6 (PRSF Additive)	203 psi / 478%
	Volume Swell	7d/200°F/JP-8+100 (Control)	6.6%
		7d/200°F/Control + #1 (RXP)	5.6%
		7d/200°F/Control + #2 (Winns)	6.1%
		7d/200°F/JP-8 + Lubrizol (PA-5)	3.6%
		7d/200°F/Control + #4 (PRSF Additive)	4.7%
		7d/200°F/Control + #5 (PRSF Additive)	5.3%
		7d/200°F/Control + #6 (PRSF Additive)	5.5%

TABLE 4 (Continued)

SEALANTS

Material Description	Test	Conditioning	Results
PR 1776 B-1/2 (AMS 3265) (Polysulfide)	Shore A Hardness	Unaged	35
		7d/200°F/JP-8+100 (Control)	30
		7d/200°F/Control + #1 (RXP)	30
		7d/200°F/Control + #2 (Winns)	29
		7d/200°F/JP-8 + Lubrizol (PA-5)	25
		7d/200°F/Control + #4 (PRSF Additive)	24
		7d/200°F/Control + #5 (PRSF Additive)	26
		7d/200°F/Control + #6 (PRSF Additive)	25
	Peel Strength (MIL-C-27725)	Unaged	36 lb / 100%
		7d/200°F/JP-8+100 (Control)	31 lb / 100%
		7d/200°F/Control + #1 (RXP)	33 lb / 100%
		7d/200°F/Control + #2 (Winns)	34 lb / 100%
		7d/200°F/JP-8 + Lubrizol (PA-5)	41 lb / 100%
		7d/200°F/Control + #4 (PRSF Additive)	35 lb / 100%
		7d/200°F/Control + #5 (PRSF Additive)	43 lb / 100%
		7d/200°F/Control + #6 (PRSF Additive)	42 lb / 100%

TABLE 5

COMPOSITES

Material Description	Test	Conditioning	Results
AS 4/3501-6 (Epoxy Graphite)	Interlaminar Shear	Unaged	11,209 psi
		7d/200°F/JP-8+100 (Control)	8962 psi
		7d/200°F/Control + #1 (RXP)	9211 psi
		7d/200°F/Control + #2 (Winns)	9188 psi
		7d/200°F/JP-8 + Lubrizol (PA-5)	9209 psi
		7d/200°F/Control + #4 (PRSF Additive)	9681 psi
		7d/200°F/Control + #5 (PRSF Additive)	9190 psi
		7d/200°F/Control + #6 (PRSF Additive)	8917 psi
IM 7/5250-4 (Graphite Bismaleimide)	Interlaminar Shear	Unaged	12,498 psi
		7d/200°F/JP-8+100 (Control)	12,490 psi
		7d/200°F/Control + #1 (RXP)	12,470 psi
		7d/200°F/Control + #2 (Winns)	11,690 psi
		7d/200°F/JP-8 + Lubrizol (PA-5)	11,980 psi
		7d/200°F/Control + #4 (PRSF Additive)	11,340 psi
		7d/200°F/Control + #5 (PRSF Additive)	11,960 psi
		7d/200°F/Control + #6 (PRSF Additive)	12,350 psi

TABLE 5 (Continued)

COMPOSITES

Material Description	Test	Conditioning	Results
AS 4/8551-7A (Epoxy Graphite)	Interlaminar Shear	Unaged	10,529 psi
		7d/200°F/JP-8+100 (Control)	11,120 psi
		7d/200°F/Control + #1 (RXP)	10,930 psi
		7d/200°F/Control + #2 (Winns)	10,375 psi
		7d/200°F/JP-8 + Lubrizol (PA-5)	9978 psi
		7d/200°F/Control + #4 (PRSF Additive)	10,790 psi
		7d/200°F/Control + #5 (PRSF Additive)	10,520 psi
		7d/200°F/Control + #6 (PRSF Additive)	10,720 psi

TABLE 6

FOAMS

Material Description	Test	Conditioning	Results
MIL-F-87260 (conductive) Foamex (Polyurethane) (Polyether)	Tensile Strength / Elongation	Unaged	13 psi / 147%
		7d/200°F/JP-8+100 (Control)	11 psi / 133%
		7d/200°F/Control + #1 (RXP)	9 psi / 152%
		7d/200°F/Control + #2 (Winns)	12 psi / 162%
		7d/200°F/JP-8 + Lubrizol (PA-5)	11 psi / 162%
		7d/200°F/Control + #4 (PRSF Additive)	11 psi / 178%
		7d/200°F/Control + #5 (PRSF Additive)	8 psi / 157%
		7d/200°F/Control + #6 (PRSF Additive)	9 psi / 152%
	Resistivity	Unaged	5.2E+08
		7d/200°F/JP-8+100 (Control)	1.1E+09
		7d/200°F/Control + #1 (RXP)	1.2E+09
		7d/200°F/Control + #2 (Winns)	2.3E+10
		7d/200°F/JP-8 + Lubrizol (PA-5)	1.4E+10
		7d/200°F/Control + #4 (PRSF Additive)	2.6E+10
		7d/200°F/Control + #5 (PRSF Additive)	2.3E+10
		7d/200°F/Control + #6 (PRSF Additive)	2.7E+10

TABLE 7

O-RINGS

Material Description	Test	Conditioning	Results
Parker N-602 (MIL-P-5315) (Nitrile)	Tensile Strength / Elongation	Unaged	1701 psi / 287%
		7d/200°F/JP-8+100 (Control)	1433 psi / 258%
		7d/200°F/Control + #1 (RXP)	1234 psi / 228%
		7d/200°F/Control + #2 (Winns)	1292 psi / 245%
		7d/200°F/JP-8 + Lubrizol (PA-5)	1492 psi / 246%
		7d/200°F/Control + #4 (PRSF Additive)	1184 psi / 224%
		7d/200°F/Control + #5 (PRSF Additive)	1504 psi / 256%
		7d/200°F/Control + #6 (PRSF Additive)	1327 psi / 241%
	Volume Swell	7d/200°F/JP-8+100 (Control)	18.1%
		7d/200°F/Control + #1 (RXP)	18.8%
		7d/200°F/Control + #2 (Winns)	16.4%
		7d/200°F/JP-8 + Lubrizol (PA-5)	16.0%
		7d/200°F/Control + #4 (PRSF Additive)	16.1%
		7d/200°F/Control + #5 (PRSF Additive)	15.9%
		7d/200°F/Control + #6 (PRSF Additive)	15.6%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker N-602 (MIL-P-5315) (Nitrile)	Shore M Hardness	Unaged	70
		7d/200°F/JP-8+100 (Control)	68
		7d/200°F/Control + #1 (RXP)	62
		7d/200°F/Control + #2 (Winns)	64
		7d/200°F/JP-8 + Lubrizol (PA-5)	60
		7d/200°F/Control + #4 (PRSF Additive)	66
		7d/200°F/Control + #5 (PRSF Additive)	61
		7d/200°F/Control + #6 (PRSF Additive)	64
	Compression Set	7d/200°F/JP-8+100 (Control)	23.5%
		7d/200°F/Control + #1 (RXP)	21.4%
		7d/200°F/Control + #2 (Winns)	22.9%
		7d/200°F/JP-8 + Lubrizol (PA-5)	11.4%
		7d/200°F/Control + #4 (PRSF Additive)	25.7%
		7d/200°F/Control + #5 (PRSF Additive)	14.3%
		7d/200°F/Control + #6 (PRSF Additive)	22.5%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker L677-70 (MIL-R-25988) (Fluorosilicone)	Tensile Strength / Elongation	Unaged	1059 psi / 220%
		7d/200°F/JP-8+100 (Control)	831 psi / 190%
		7d/200°F/Control + #1 (RXP)	790 psi / 175%
		7d/200°F/Control + #2 (Winns)	706 psi / 187%
		7d/200°F/JP-8 + Lubrizol (PA-5)	739 psi / 168%
		7d/200°F/Control + #4 (PRSF Additive)	763 psi / 179%
		7d/200°F/Control + #5 (PRSF Additive)	822 psi / 190%
		7d/200°F/Control + #6 (PRSF Additive)	831 psi / 191%
	Volume Swell	7d/200°F/JP-8+100 (Control)	13.9%
		7d/200°F/Control + #1 (RXP)	14.4%
		7d/200°F/Control + #2 (Winns)	13.4%
		7d/200°F/JP-8 + Lubrizol (PA-5)	13.7%
		7d/200°F/Control + #4 (PRSF Additive)	13.2%
		7d/200°F/Control + #5 (PRSF Additive)	13.6%
		7d/200°F/Control + #6 (PRSF Additive)	13.5%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker L677-70 (MIL-R-25988) (Fluorosilicone)	Shore M Hardness	Unaged	68
		7d/200°F/JP-8+100 (Control)	65
		7d/200°F/Control + #1 (RXP)	65
		7d/200°F/Control + #2 (Winns)	65
		7d/200°F/JP-8 + Lubrizol (PA-5)	60
		7d/200°F/Control + #4 (PRSF Additive)	64
		7d/200°F/Control + #5 (PRSF Additive)	63
		7d/200°F/Control + #6 (PRSF Additive)	63
	Compression Set	7d/200°F/JP-8+100 (Control)	8.5%
		7d/200°F/Control + #1 (RXP)	4.2%
		7d/200°F/Control + #2 (Winns)	4.3%
		7d/200°F/JP-8 + Lubrizol (PA-5)	2.9%
		7d/200°F/Control + #4 (PRSF Additive)	4.2%
		7d/200°F/Control + #5 (PRSF Additive)	8.4%
		7d/200°F/Control + #6 (PRSF Additive)	3.0%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker VO-835 (MIL-R-83485) (Fluorocarbon) (Viton GLT)	Tensile Strength / Elongation	Unaged	1583 psi / 183%
		7d/325°F/JP-8+100 (Control)	1292 psi / 165%
		7d/325°F/Control + #1 (RXP)	1311 psi / 178%
		7d/325°F/Control + #2 (Winns)	1299 psi / 175%
		7d/325°F/JP-8 + Lubrizol (PA-5)	1228 psi / 160%
		7d/325°F/Control + #4 (PRSF Additive)	1326 psi / 170%
		7d/325°F/Control + #5 (PRSF Additive)	1248 psi / 173%
		7d/325°F/Control + #6 (PRSF Additive)	1209 psi / 179%
	Volume Swell	7d/325°F/JP-8+100 (Control)	6.3%
		7d/325°F/Control + #1 (RXP)	6.7%
		7d/325°F/Control + #2 (Winns)	6.7%
		7d/325°F/JP-8 + Lubrizol (PA-5)	6.5%
		7d/325°F/Control + #4 (PRSF Additive)	7.0%
		7d/325°F/Control + #5 (PRSF Additive)	6.9%
		7d/325°F/Control + #6 (PRSF Additive)	7.2%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker VO-835 (MIL-R-83485) (Fluorocarbon) (Viton GLT)	Shore M Hardness	Unaged	76
		7d/325°F/JP-8+100 (Control)	71
		7d/325°F/Control + #1 (RXP)	74
		7d/325°F/Control + #2 (Winns)	73
		7d/325°F/JP-8 + Lubrizol (PA-5)	58
		7d/325°F/Control + #4 (PRSF Additive)	72
		7d/325°F/Control + #5 (PRSF Additive)	60
		7d/325°F/Control + #6 (PRSF Additive)	59
	Compression Set	7d/325°F/JP-8+100 (Control)	27.1%
		7d/325°F/Control + #1 (RXP)	22.8%
		7d/325°F/Control + #2 (Winns)	24.3%
		7d/325°F/JP-8 + Lubrizol (PA-5)	25.7%
		7d/325°F/Control + #4 (PRSF Additive)	28.6%
		7d/325°F/Control + #5 (PRSF Additive)	30.0%
		7d/325°F/Control + #6 (PRSF Additive)	28.6%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker V 1226-75 (MIL-R-83248) (Fluorocarbon)	Tensile Strength / Elongation	Unaged	1799 psi / 229%
		7d/325°F/JP-8+100 (Control)	1534 psi / 218%
		7d/325°F/Control + #1 (RXP)	1590 psi / 230%
		7d/325°F/Control + #2 (Winns)	1484 psi / 206%
		7d/325°F/JP-8 + Lubrizol (PA-5)	1703 psi / 256%
		7d/325°F/Control + #4 (PRSF Additive)	1630 psi / 226%
		7d/325°F/Control + #5 (PRSF Additive)	1612 psi / 261%
		7d/325°F/Control + #6 (PRSF Additive)	1578 psi / 241%
	Volume Swell	7d/325°F/JP-8+100 (Control)	7.4%
		7d/325°F/Control + #1 (RXP)	6.0%
		7d/325°F/Control + #2 (Winns)	6.4%
		7d/325°F/JP-8 + Lubrizol (PA-5)	6.4%
		7d/325°F/Control + #4 (PRSF Additive)	7.0%
		7d/325°F/Control + #5 (PRSF Additive)	7.2%
		7d/325°F/Control + #6 (PRSF Additive)	6.6%

TABLE 7 (Continued)

O-RINGS

Material Description	Test	Conditioning	Results
Parker V 1226-75 (MIL-R-83248) (Fluorocarbon)	Shore M Hardness	Unaged	76
		7d/325°F/JP-8+100 (Control)	63
		7d/325°F/Control + #1 (RXP)	65
		7d/325°F/Control + #2 (Winns)	65
		7d/325°F/JP-8 + Lubrizol (PA-5)	56
		7d/325°F/Control + #4 (PRSF Additive)	63
		7d/325°F/Control + #5 (PRSF Additive)	65
		7d/325°F/Control + #6 (PRSF Additive)	64
	Compression Set	7d/325°F/JP-8+100 (Control)	17.1%
		7d/325°F/Control + #1 (RXP)	17.1%
		7d/325°F/Control + #2 (Winns)	31.4%
		7d/325°F/JP-8 + Lubrizol (PA-5)	21.5%
		7d/325°F/Control + #4 (PRSF Additive)	17.1%
		7d/325°F/Control + #5 (PRSF Additive)	44.3%
		7d/325°F/Control + #6 (PRSF Additive)	28.6%

TABLE 8

HOSES

Material Description	Test	Conditioning	Results
AC-603-01 (MIL-H-4495) (Acrylic/Nitrile)	Tensile Strength / Elongation	Unaged	1486 psi / 282%
		7d/200°F/JP-8+100 (Control)	1090 psi / 192%
		7d/200°F/Control + #1 (RXP)	1030 psi / 194%
		7d/200°F/Control + #2 (Winns)	1068 psi / 174%
		7d/200°F/JP-8 + Lubrizol (PA-5)	1233 psi / 225%
		7d/200°F/Control + #4 (PRSF Additive)	1308 psi / 198%
		7d/200°F/Control + #5 (PRSF Additive)	1042 psi / 191%
		7d/200°F/Control + #6 (PRSF Additive)	981 psi / 187%
	Volume Swell	7d/200°F/JP-8+100 (Control)	7.0%
		7d/200°F/Control + #1 (RXP)	6.1%
		7d/200°F/Control + #2 (Winns)	7.7%
		7d/200°F/JP-8 + Lubrizol (PA-5)	6.3%
		7d/200°F/Control + #4 (PRSF Additive)	7.3%
		7d/200°F/Control + #5 (PRSF Additive)	5.4%
		7d/200°F/Control + #6 (PRSF Additive)	4.9%

TABLE 8 (Continued)

HOSES

Material Description	Test	Conditioning	Results
AC-603-01 (MIL-H-4495) (Acrylic/Nitrile)	Shore A Hardness	Unaged	56
		7d/200°F/JP-8+100 (Control)	52
		7d/200°F/Control + #1 (RXP)	50
		7d/200°F/Control + #2 (Winns)	53
		7d/200°F/JP-8 + Lubrizol (PA-5)	55
		7d/200°F/Control + #4 (PRSF Additive)	53
		7d/200°F/Control + #5 (PRSF Additive)	53
		7d/200°F/Control + #6 (PRSF Additive)	54
EC-614-01 (MIL-H-26521) (Nitrile)	Tensile Strength / Elongation	Unaged	1443 psi / 481%
		7d/200°F/JP-8+100 (Control)	1368 psi / 339%
		7d/200°F/Control + #1 (RXP)	1238 psi / 319%
		7d/200°F/Control + #2 (Winns)	1387 psi / 297%
		7d/200°F/JP-8 + Lubrizol (PA-5)	1344 psi / 331%
		7d/200°F/Control + #4 (PRSF Additive)	1361 psi / 378%
		7d/200°F/Control + #5 (PRSF Additive)	1239 psi / 314%
		7d/200°F/Control + #6 (PRSF Additive)	1296 psi / 335%

TABLE 8 (Continued)

HOSES

Material Description	Test	Conditioning	Results
	Volume Swell	7d/200°F/JP-8+100 (Control)	8.1%
		7d/200°F/Control + #1 (RXP)	7.9%
		7d/200°F/Control + #2 (Winns)	9.1%
		7d/200°F/JP-8 + Lubrizol (PA-5)	8.0%
		7d/200°F/Control + #4 (PRSF Additive)	8.5%
		7d/200°F/Control + #5 (PRSF Additive)	7.6%
		7d/200°F/Control + #6 (PRSF Additive)	8.0%
EC-614-01 (MIL-H-26521) (Nitrile)	Shore A Hardness	Unaged	59
		7d/200°F/JP-8+100 (Control)	53
		7d/200°F/Control + #1 (RXP)	51
		7d/200°F/Control + #2 (Winns)	52
		7d/200°F/JP-8 + Lubrizol (PA-5)	57
		7d/200°F/Control + #4 (PRSF Additive)	52
		7d/200°F/Control + #5 (PRSF Additive)	56
		7d/200°F/Control + #6 (PRSF Additive)	56

TABLE 9

WIRE INSULATION

Material Description	Test	Conditioning	Results
TFE Teflon Film	Tensile Strength / Elongation	Unaged	1842 psi / 249%
		7d/200°F/JP-8+100 (Control)	1825 psi / 191%
		7d/200°F/Control + #1 (RXP)	1811 psi / 219%
		7d/200°F/Control + #2 (Winns)	1851 psi / 186%
		7d/200°F/JP-8 + Lubrizol (PA-5)	1941 psi / 161%
		7d/200°F/Control + #4 (PRSF Additive)	1839 psi / 164%
		7d/200°F/Control + #5 (PRSF Additive)	1812 psi / 212%
		7d/200°F/Control + #6 (PRSF Additive)	1787 psi / 173%
Polyethylene Film	Tensile Strength / Elongation	Unaged	3757 psi / 182%
		7d/200°F/JP-8+100 (Control)	2973 psi / 229%
		7d/200°F/Control + #1 (RXP)	2987 psi / 178%
		7d/200°F/Control + #2 (Winns)	2788 psi / 295%
		7d/200°F/JP-8 + Lubrizol (PA-5)	3010 psi / 250%
		7d/200°F/Control + #4 (PRSF Additive)	2841 psi / 279%
		7d/200°F/Control + #5 (PRSF Additive)	3005 psi / 197%
		7d/200°F/Control + #6 (PRSF Additive)	2962 psi / 246%

TABLE 9 (Continued)

WIRE INSULATION

Material Description	Test	Conditioning	Results
Dupont Zytel 101 Film (Nylon 101)	Tensile Strength / Elongation	Unaged	10,700 psi / 313%
		7d/200°F/JP-8+100 (Control)	12,543 psi / 280%
		7d/200°F/Control + #1 (RXP)	12,623 psi / 285%
		7d/200°F/Control + #2 (Winns)	12,593 psi / 133%
		7d/200°F/JP-8 + Lubrizol (PA-5)	12,818 psi / 358%
		7d/200°F/Control + #4 (PRSF Additive)	13,388 psi / 137%
		7d/200°F/Control + #5 (PRSF Additive)	12,979 psi / 240%
		7d/200°F/Control + #6 (PRSF Additive)	12,928 psi / 256%
UPILEX Film (Kapton)	Tensile Strength / Elongation	Unaged	15,080 psi / 24%
		7d/200°F/JP-8+100 (Control)	15,211 psi / 29%
		7d/200°F/Control + #1 (RXP)	14,901 psi / 30%
		7d/200°F/Control + #2 (Winns)	15,634 psi / 40%
		7d/200°F/JP-8 + Lubrizol (PA-5)	14,520 psi / 40%
		7d/200°F/Control + #4 (PRSF Additive)	14,675 psi / 36%
		7d/200°F/Control + #5 (PRSF Additive)	14,730 psi / 40%
		7d/200°F/Control + #6 (PRSF Additive)	15,198 psi / 40%